
The search for young massive clusters in our Galaxy
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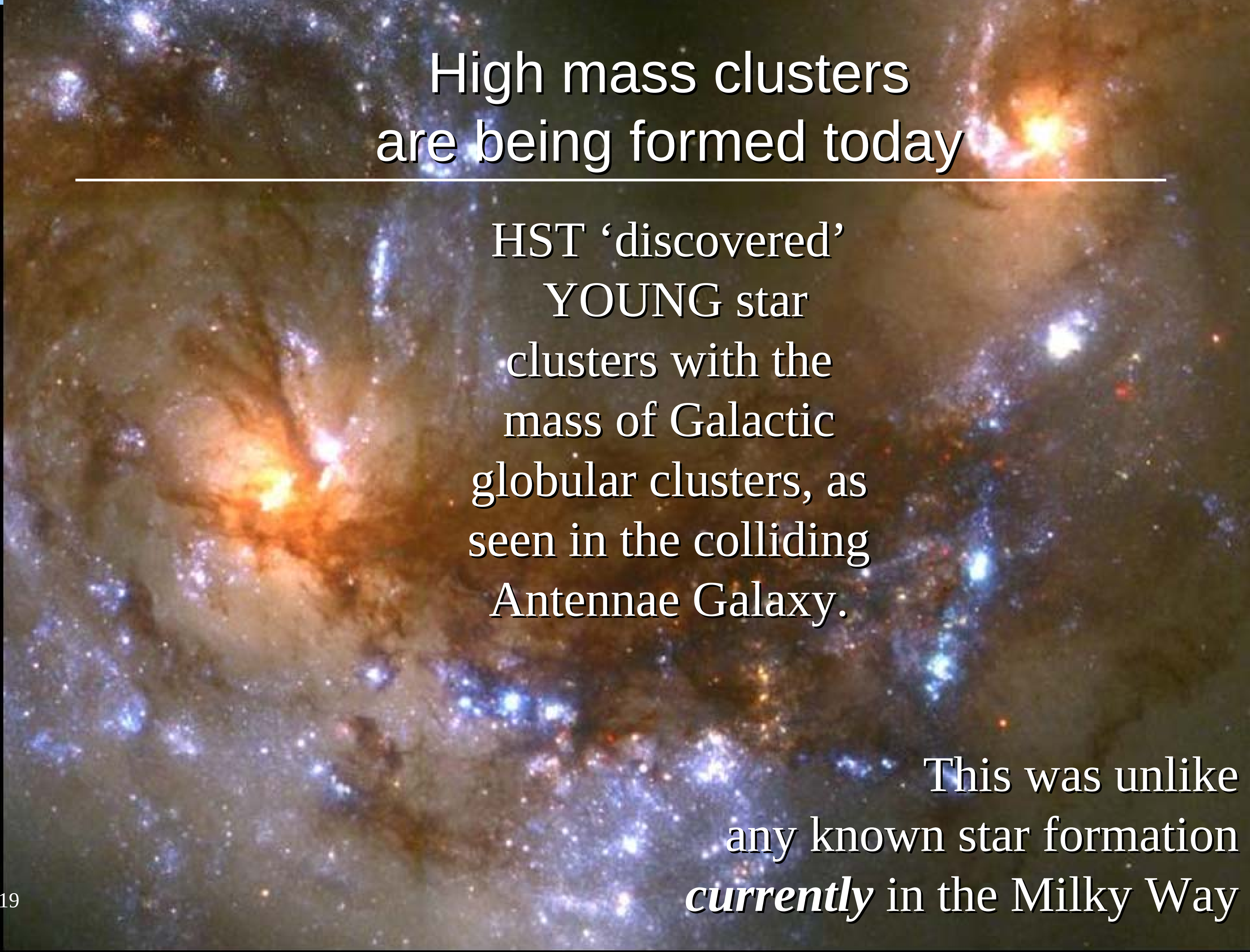


High mass clusters are being formed today

HST ‘discovered’ YOUNG star clusters with the mass of Galactic globular clusters, as seen in the colliding Antennae Galaxy.

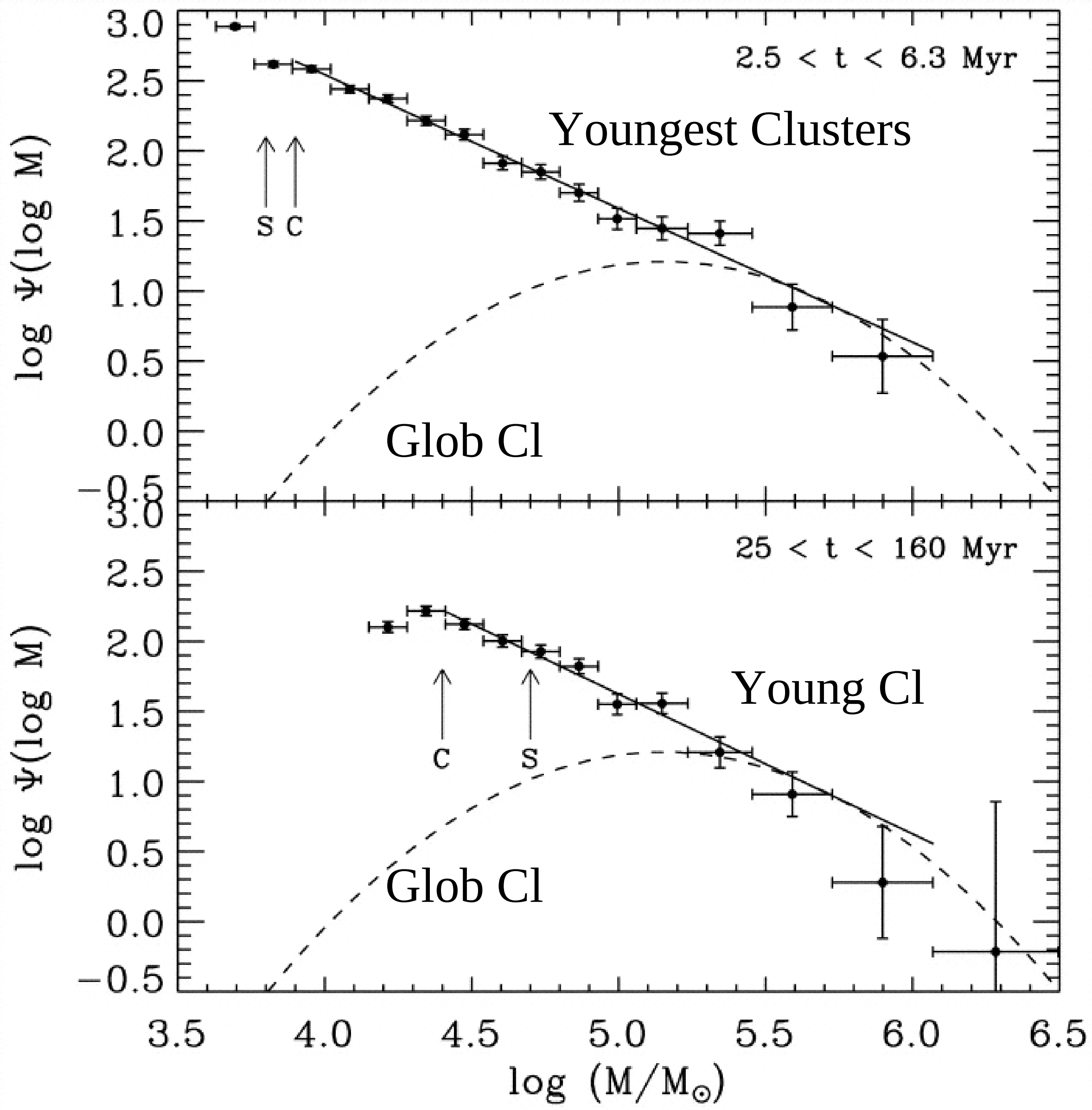
This was unlike any known star formation ***currently*** in the Milky Way

Extragalactic Young Massive Clusters

Zhang & Fall (1999)

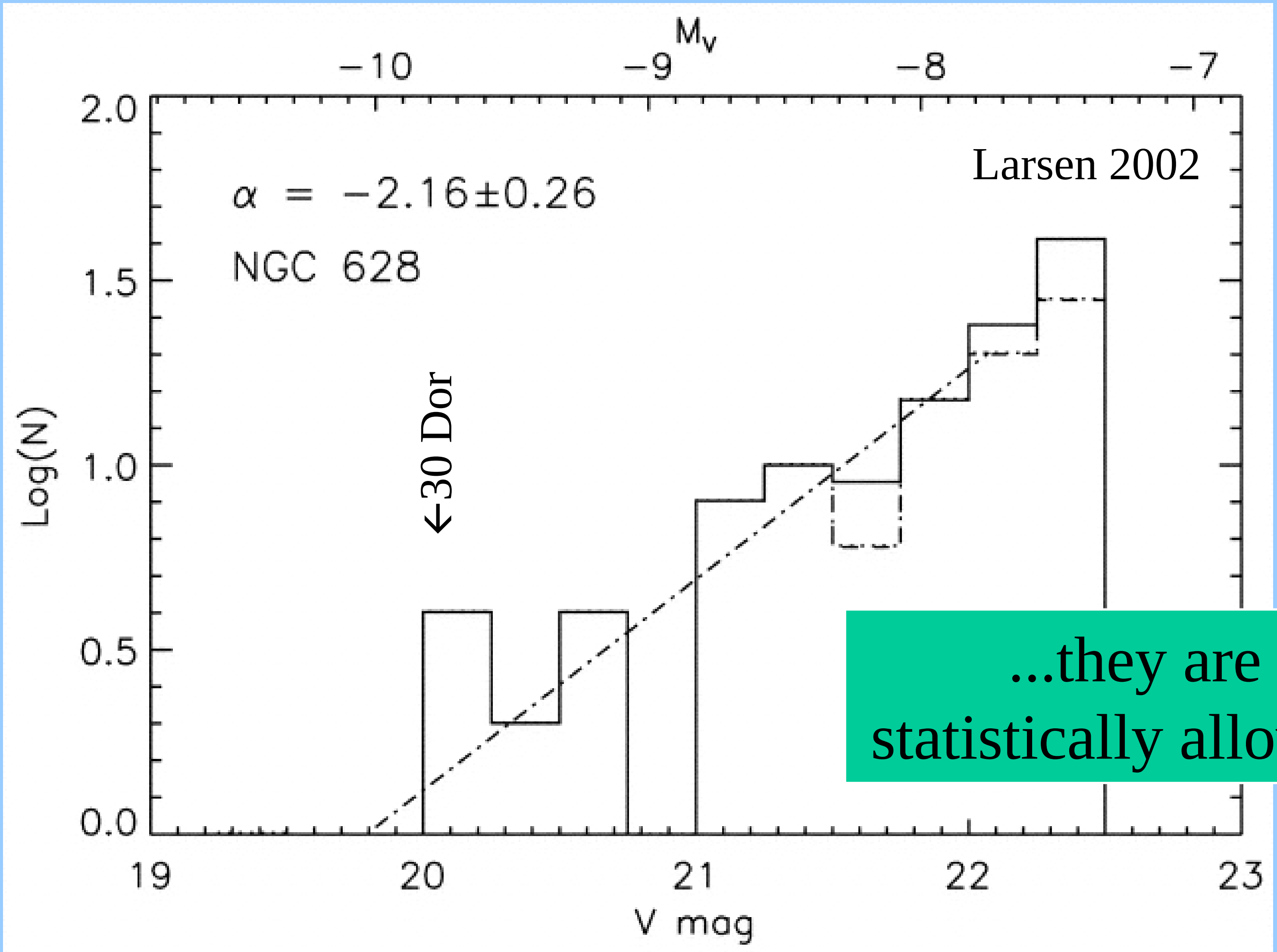
Found clusters with the masses of Galactic globulars, but only tens of millions years old.

The number of clusters follows a power law, slope -2, over the mass range
$10^4 < M < 10^6$



But don't you need mergers to make very massive young clusters?

No! Isolated spiral galaxies will show massive young clusters. Provided..



...they are statistically allowed.

Does such a power law apply to clusters in the Milky Way?

The cluster luminosity function:

- Most massive: few x 10^3 Mo
- Survey's are complete to 1-2 kpc
- Number of clusters as fxn of Mv, is a power law, slope -2
- The present day Globular Clusters follow a similar power law (see Harris & Pudritz 1994)

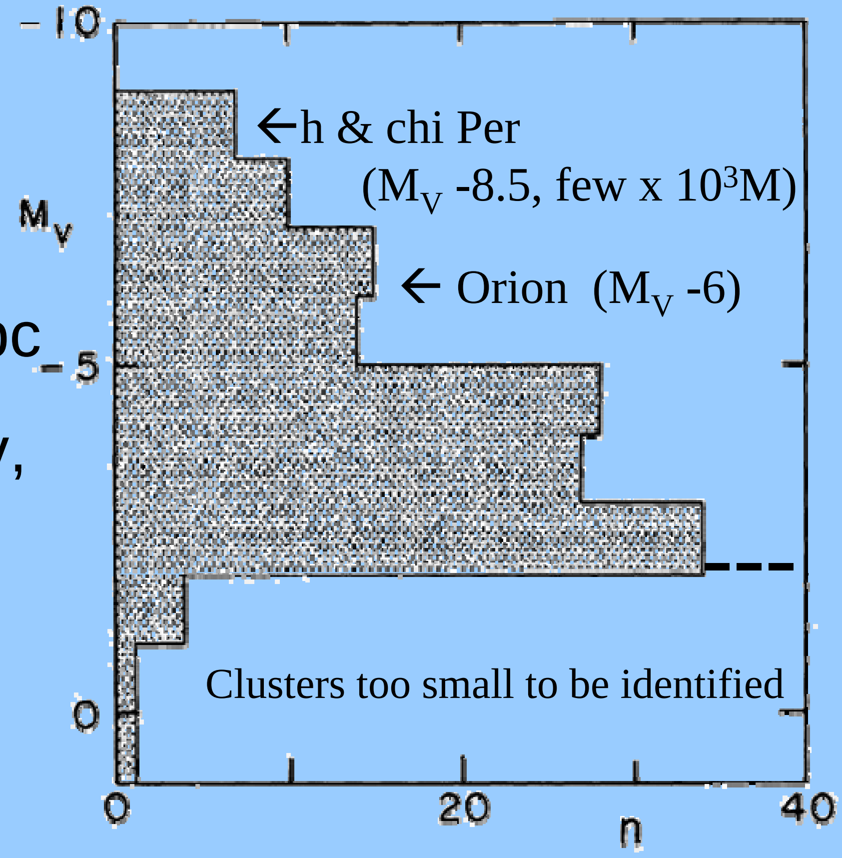
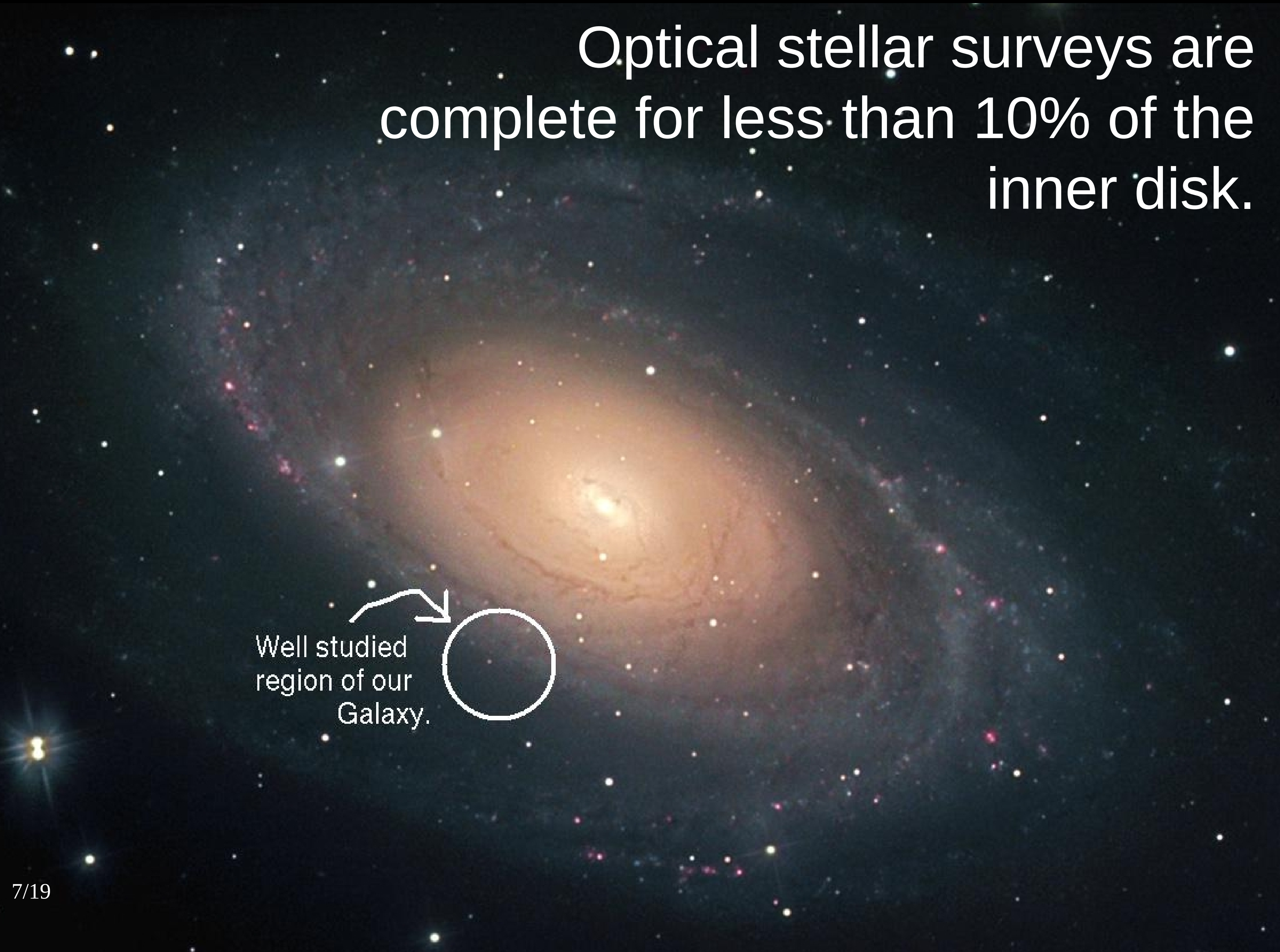


FIG. 1. Luminosity distribution of clusters contained in the catalog of Sagar *et al.* The paucity of clusters fainter than $M_v = -2$ is probably due to selection effects.

van den Bergh & Lafontaine (1984)

Optical stellar surveys are complete for less than 10% of the inner disk.



What if we could see our whole Galaxy?

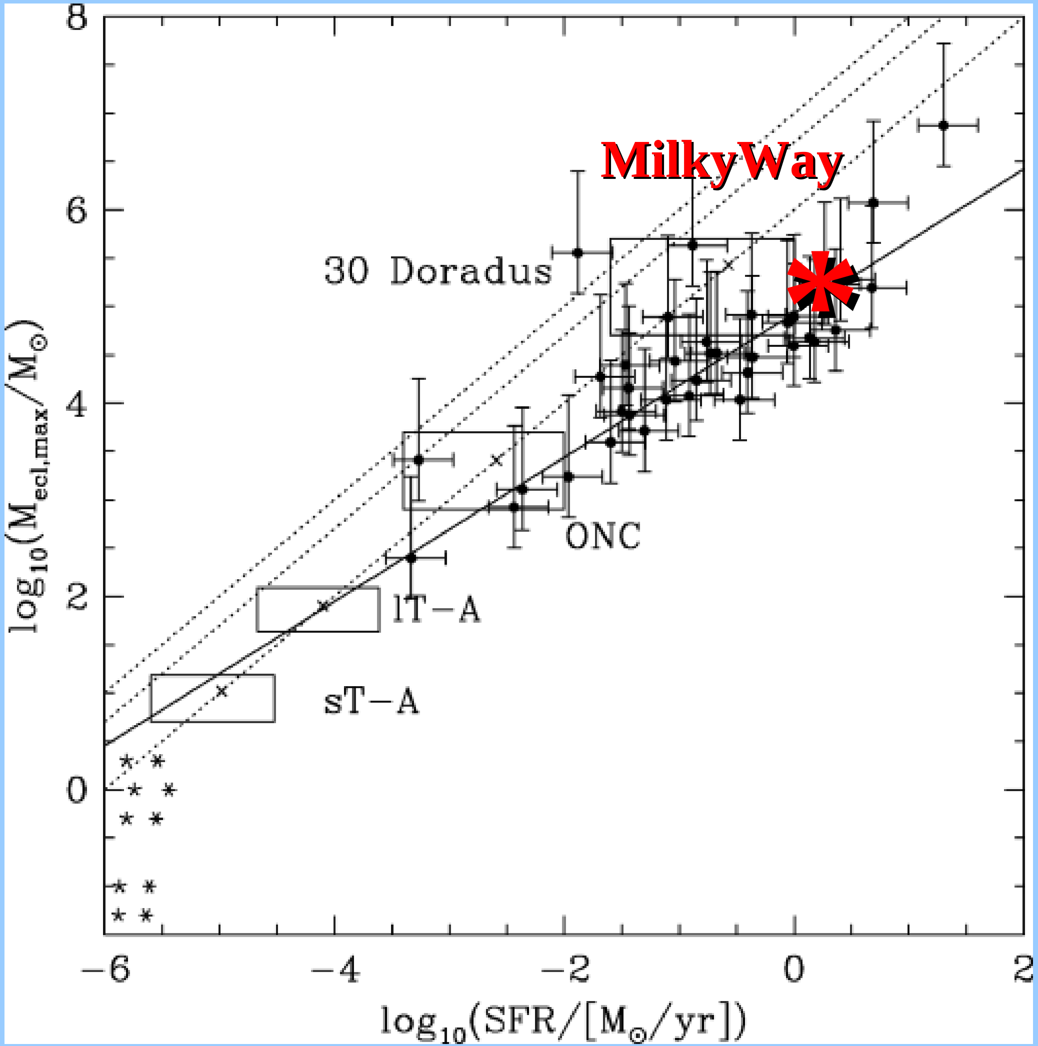
The locally derived, luminosity function of Milky Way star clusters ***predicts*** (vdB & Lf 1984):

- **100** clusters will have M_V = -11 (M=10^4 Msun)
- A few clusters will have M_V < -12 (M>/=10^5 Msun)

<u>van den Bergh & Lafontaine 1984:</u>

"It is hard to believe the Galaxy contains so many undiscovered super luminous open clusters. This suggests that the luminosity function of galactic clusters starts to fall below the extrapolation in the range -11 < Mv < -8."

If we are a normal galaxy, the Milky Way will contain 'Super Star Clusters'.



External galaxies show a correlation between the SFR rate and the most massive ***young*** cluster found.

If the Milky Way is like other galaxies, the most massive clusters predicted to form are $M \sim 10^5 - 10^6$ Msun

Weidner *et. al* 2004

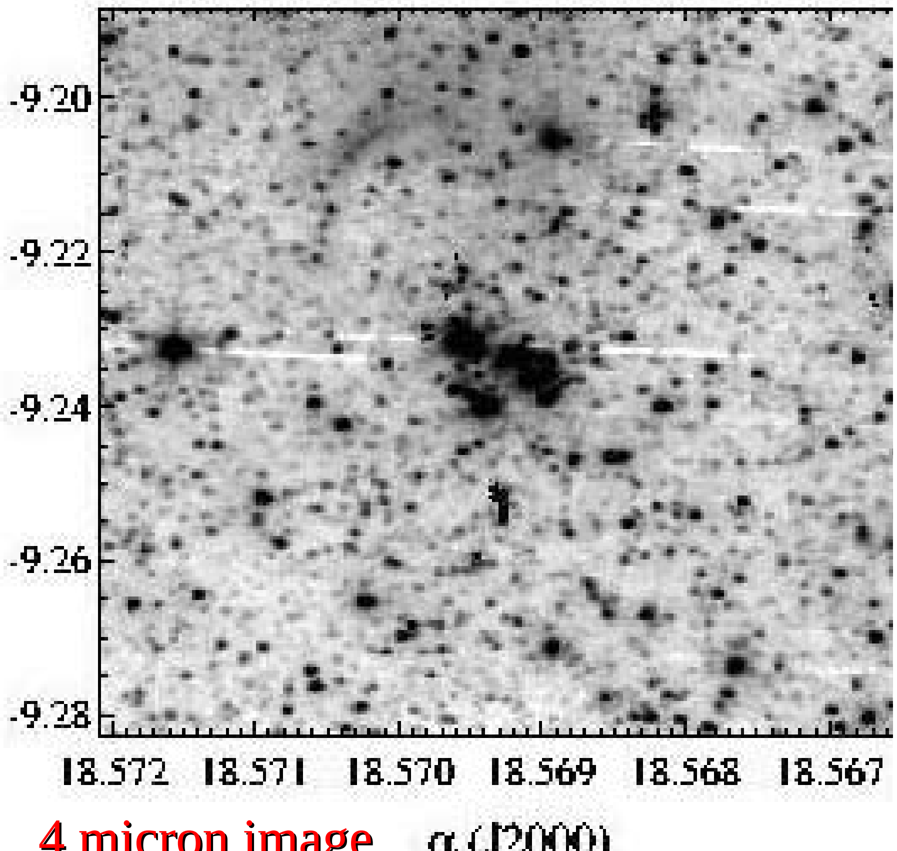
How do we find these massive clusters?

Numerous cluster searches based on 2MASS exist:
Bica, Dutra, et al. set of surveys (2001, 2003, etc)
Froebrich et al. (2007) found >1000 new IR Clusters.

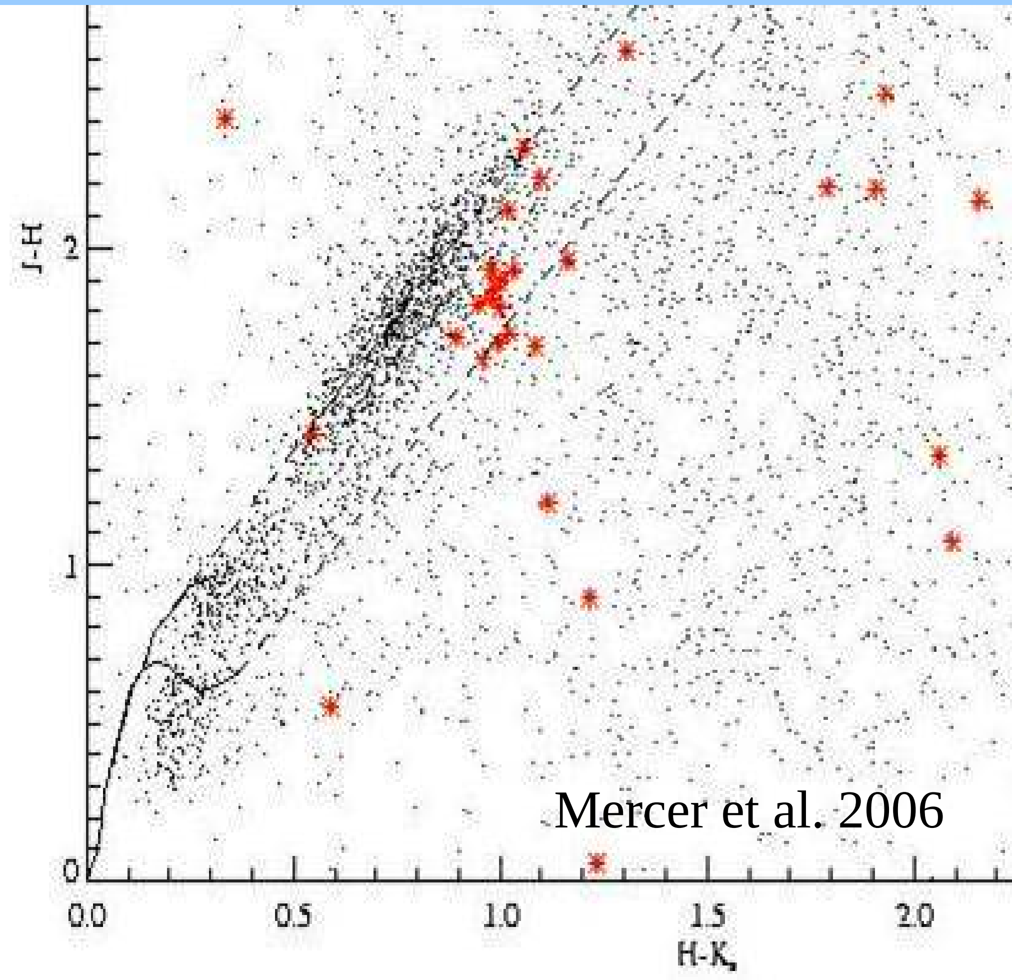
Our search uses GLIMPSE:

- GLIMPSE: completed in 2005, uses the Spitzer Space Telescope
- Four bands (3, 4.5, 6, 8 microns)
- Covers inner Galactic disk: longitude = $|65^o|$, latitude = $|1^o|$
- Probes deeper than 2MASS
- Mercer et al. (2005) have identified almost 100 new clusters.

Young, `Blue' clusters found with GLIMPSE

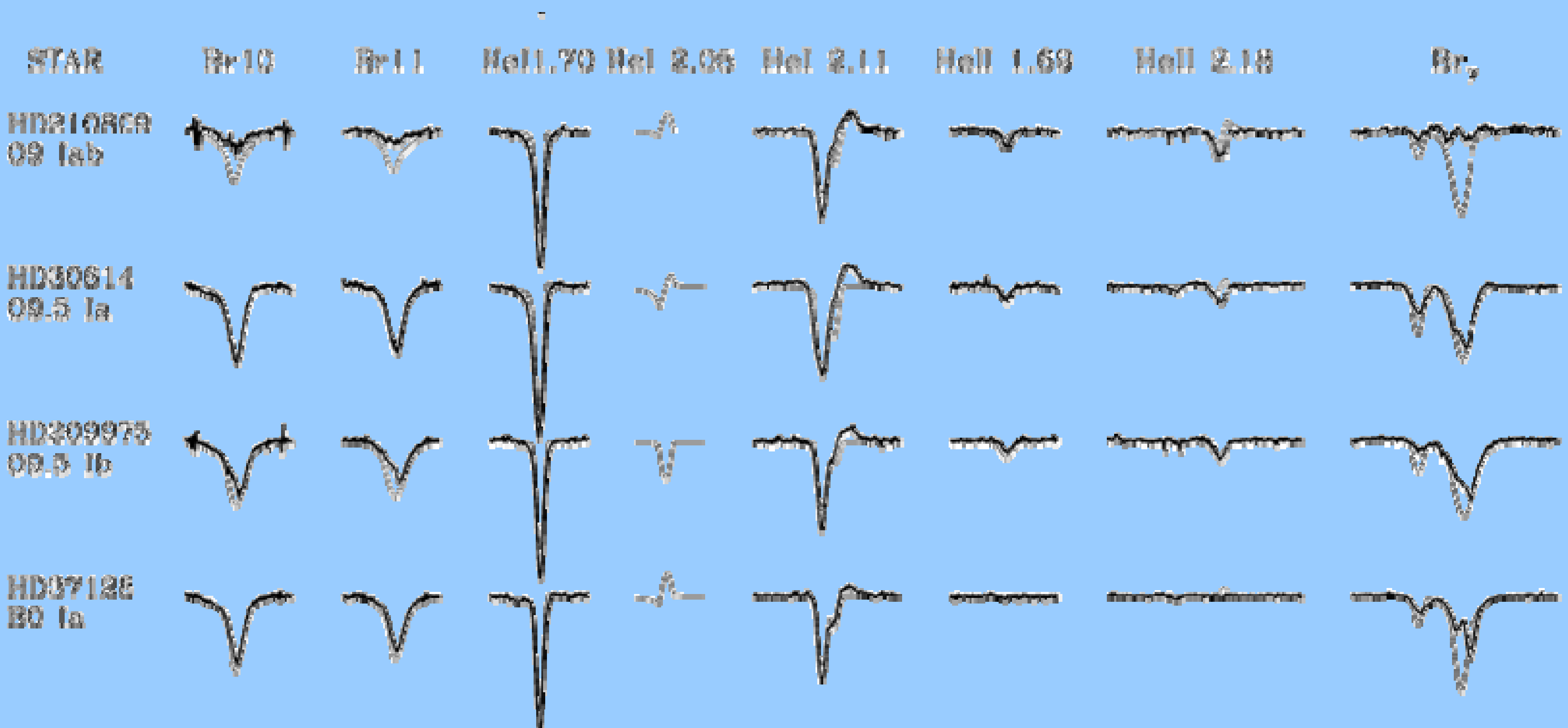


4 micron image α (J2000)



Small concentration of stars (*) show similar `blue color' indicating a young, luminous cluster. Av=15

Spectra of Hot Stars at 2 microns



We (Cincinnati/Munich) have a sophisticated atmospheric code that provides quantitative spectral analysis of hot stars ***using near-infrared spectra alone.***

Westerlund 1, M_v = -11(-12?)

M ~ 10^5 Suns (Clark et al. 2005)

Av = 11.5, Distance = 4-5 kpc

Search selection biases are not understood

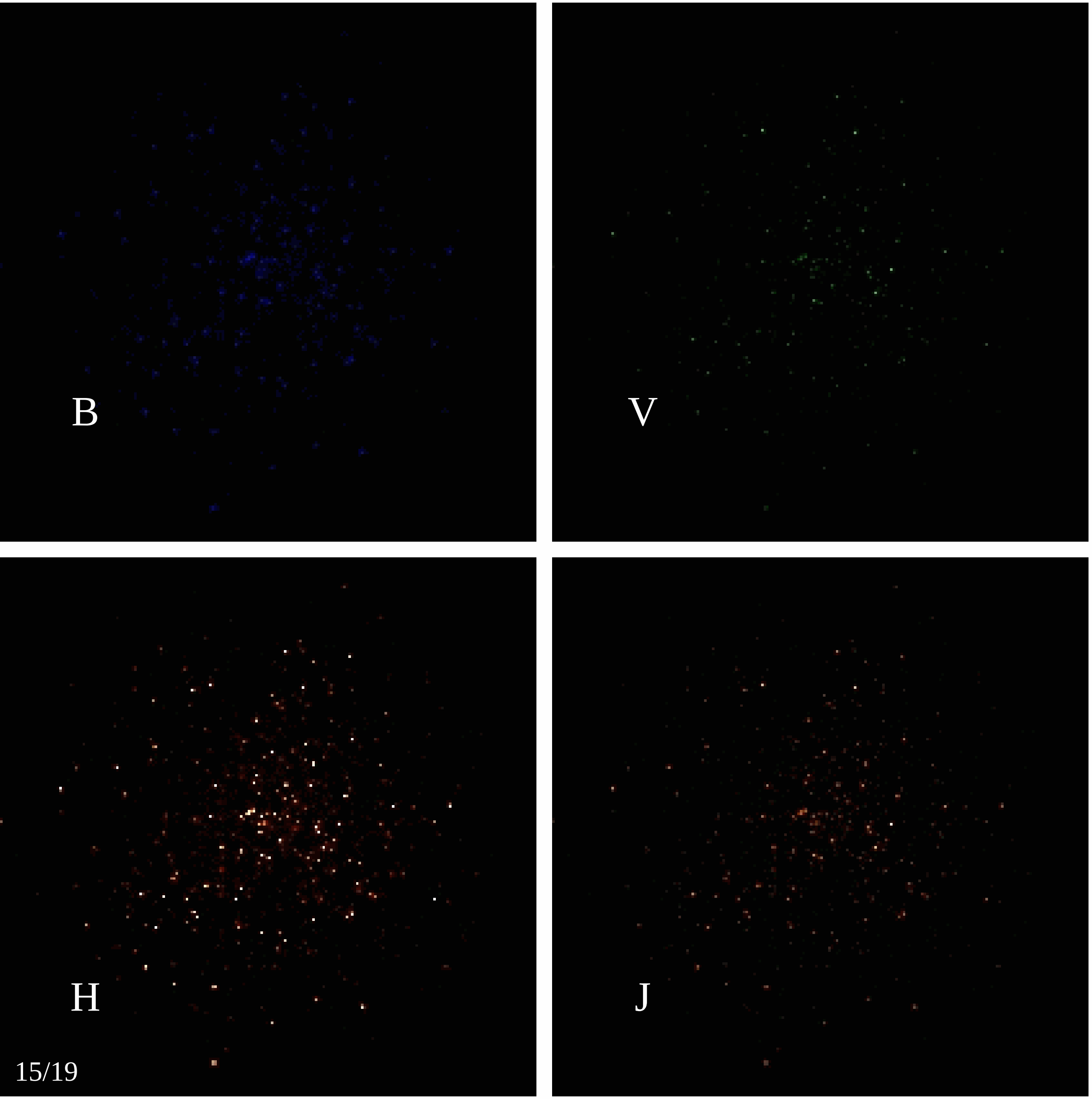
Might there be a high mass cut off among massive clusters, like has been proposed with high mass stars?

Gieles et al. (2006) on the Milky Way:

``Assuming the number density of clusters is constant out to Wd 1 (4.5 kpc).. We would expect at least one cluster above 10^6 Mo. ..it is unlikely that a 10 times more massive object would not have been found yet within 4.5 kpc of the Sun. Wd1 is a reasonable upper limit [for the Milky Way].''

Unfortunately, the selection effects of current search methods are not well enough constrained to be sure.

Our Cluster Simulations demonstrate Biases



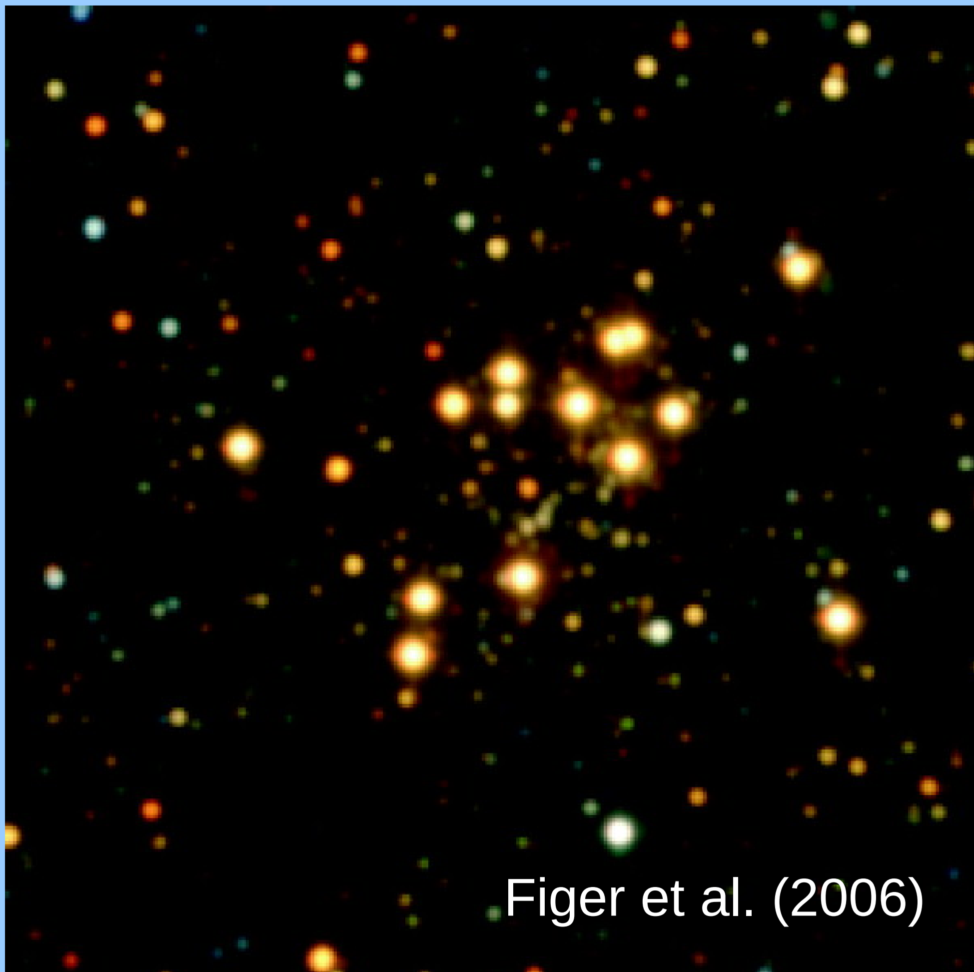
Westerlund 1 Simulation:
Mass = 10^5 Msun
Extinction: Av = 11
With mass segregation

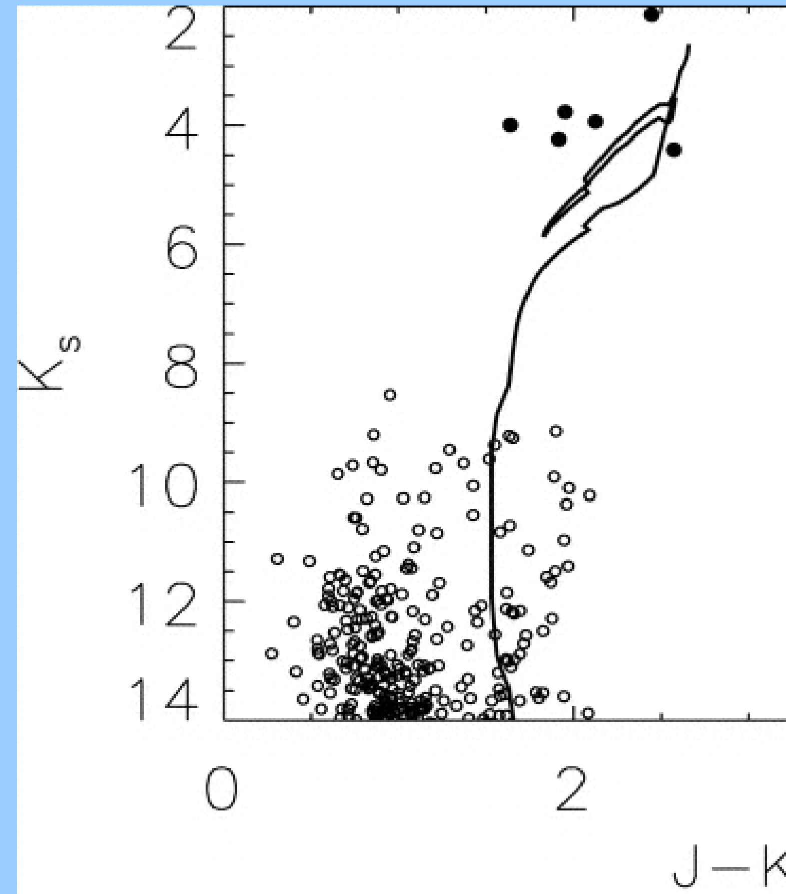
Log(T) = 6.0 to 8.0 yr

With significant extinction, NIR is clearly required, but NIR searches are much more ***age sensitive*** than the optical.

Popescu & Hanson 2007

What will NIR searches uncover?





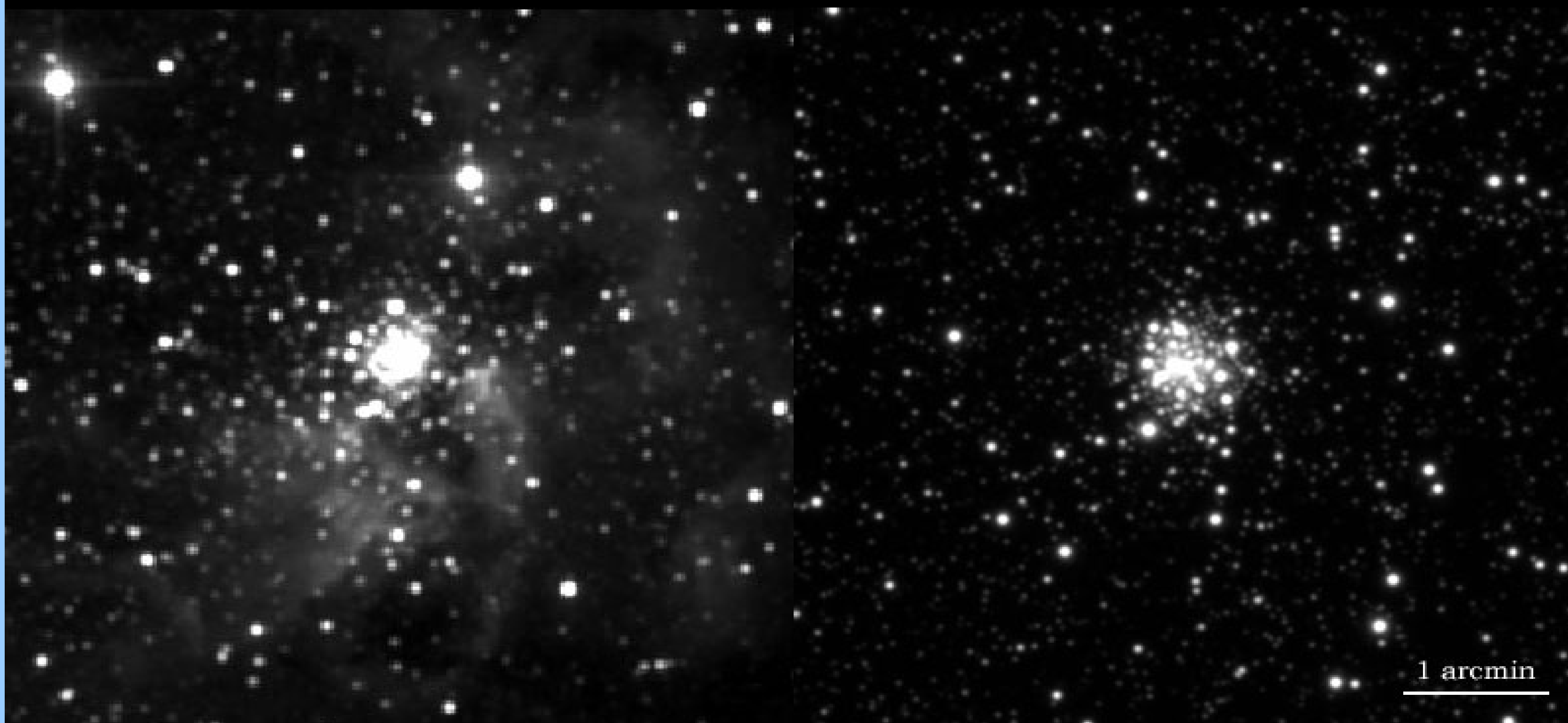
Found with 2MASS
(CL 122 Dutra et al. 2003)

Cited cluster properties:
14 RSG, 1 YSG, 10^4-10^5 M_o
Few x 10^6 yrs, ~5 kpc, Av=30

Calibrating our simulations to known clusters

NGC 3603, J-Band Image

Stolte et al. (2004): $2x10^6$ yrs, $7x10^3$ M, Av=4.5, 6 kpc



2 MASS
J-Band Image

(B Popescu & M Hanson, 2007,
MASSCLEAN + SkyMaker)


MASSCLEAN
MASSive CLuster Evolution and ANalysis Package
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Future Research Goals

- Continue with near-infrared observations to uncover and characterize the massive clusters of the inner Milky Way.
- Simulate the Milky Way plane with massive clusters and use current NIR cluster search methods to estimate the number of massive clusters missed as fxn of mass, age, distance, Av, cluster density, etc.
- Characterize resolved Local Group SSCs, compare with Starburst99/GALAXEV and strengthen models for distant unresolved SSC in other galaxies.

Input : Mass of the cluster (in solar units)

generator

n_distribution

Compute the mass distribution (using Kroupe IMF).

writeindex

index_trek

trek

Read the isochrones files from the Geneva Database.
Compute the photometric quantities for all the stars in the distribution and for all ages in the isochrones.

Input : King Model parameters (r_t , r_c)

random_king

Computes the King Model distribution.

Input : A_V , R_V

ccm_extinction

Computes CCM extinction curves.

Input : distance (pc)

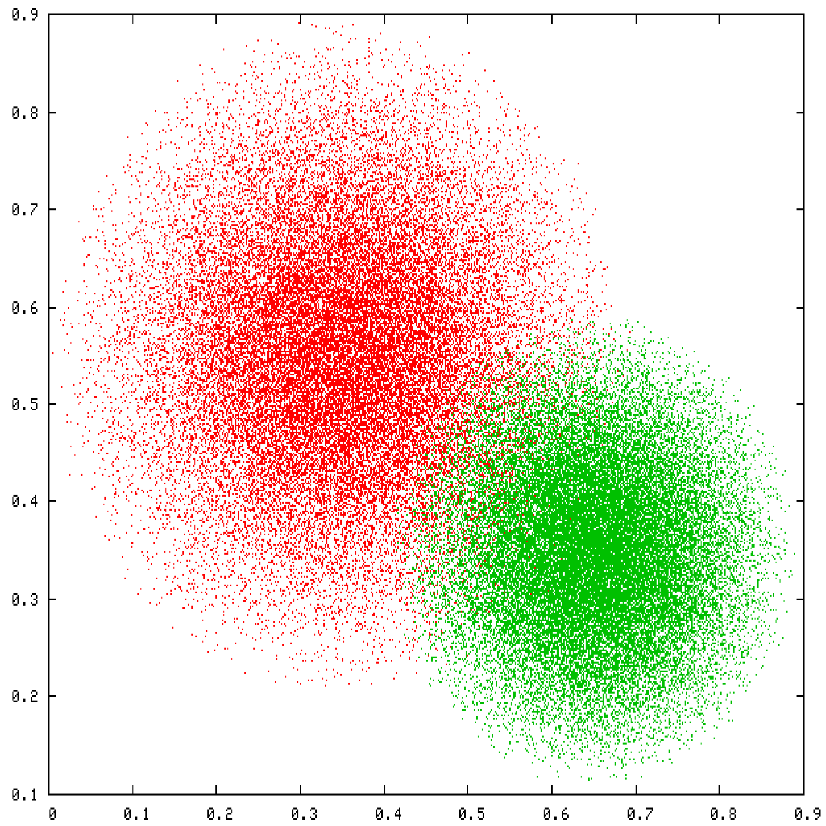
Optional input : anisotropy parameters for King Model, rescaling parameters for multiple King clusters, mass segregation parameters, different values for extinction

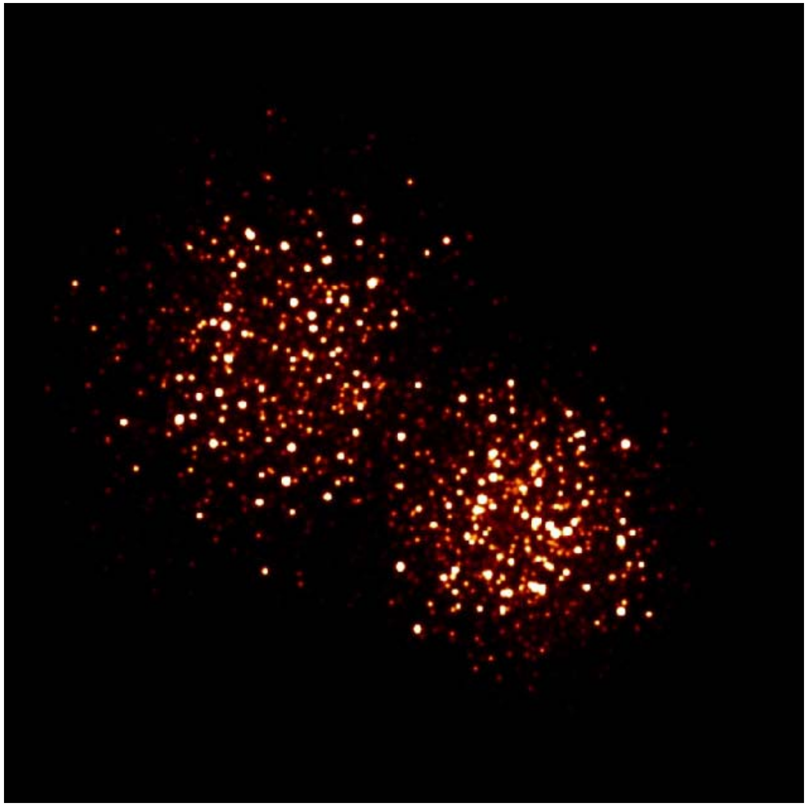
Additional input : FOV, image size

star_sky

Computes positions and magnitudes (UBVRIJHK) for all stars and all ages (log(T)=3.0..10.2).
Writes files for HR diagrams, color-magnitude diagrams, input files for SkyMaker (to generate FITS images).

Rescaling for multiple clusters (like H & Chi Persei)





MASSCLEAN 1.00 (MASSive CLuster Evolution and ANalysis Package)
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MASSCLEAN 1.00 is freely available at :

http://www.physics.uc.edu/~popescu/

http://homepages.uc.edu/~popescb/

Very luminous young clusters make excellent nearby analogues of distant Super Star Clusters

SSCs in the ‘Antennae’ galaxy (Snijders et al. 2006)